Circular No. 613

September 1941 • Washington, D. C.

UNITED STATES DEPARTMENT OF AGRICULTURE

Studies on the Respiration of Strawberry and Raspberry Fruits [1]

By Mark H. Haller, *associate pomologist*, Dean H. Rose, *senior physiologist*, and Paul L. Harding, *associate horticulturist, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry*

CONTENTS

INTRODUCTION

The respiratory intensity of fruit is of much interest from the standpoint of storage and handling. Respiratory intensity is a measure of the rate at which metabolism is proceeding, and as such is often considered an indication of the potential storage life of the fruit, a high respiratory intensity being associated with a short storage life. As a measure of metabolism, respiratory intensity may also give an indication of the rate at which the fruit is deteriorating in dessert quality and food value. From the respiratory rate it is also possible to estimate the heat of respiration, which under some conditions may be an important factor in the refrigeration of a product. Data on the respiration of strawberries, and to a limited extent of raspberries, are presented in this circular, and their relation to handling practices and to deterioration of the fruit is discussed.

MATERIAL AND METHODS

The source of the fruit and the treatments applied are described in the presentation of results for the different experiments.

The method of determining the rate of respiration has been described previously by Haller and Rose (*4*)[2] and is a modification of that de-

[1] Submitted for publication February 1941.

[2] Italic numbers in parentheses refer to Literature Cited, p. 13.

scribed by Magness and Diehl (*5*). The equipment consists of a respiration chamber, generally a desiccator, to which is attached a cylinder of O_2. The chamber has a vessel for a CO_2 absorbent—in this case 2N. KOH solution—so installed that the absorbent may be removed and replaced without opening the chamber. As the O_2 is used by the fruit it is replaced by O_2 from the cylinder, which in turn is replaced by water, the entire system being closed and at atmospheric pressure. This is a static system and depends on diffusion of the CO_2 evolved to the surface of the absorbent as contrasted with dynamic systems in which the CO_2 is absorbed by aspirating the gas from the chamber through a tube of dry absorbent, or through a tower of absorbing solution.

Masure (*6*) has compared these three methods of measuring the CO_2 evolved and found that the static-diffusion ("desiccator") method gave intermediate results, with the tower-solution method higher (mean of 5.8 percent for four runs but with insignificant differences in two of them), and the dry-absorbent method lower. Solely on the basis of the higher readings obtained by the tower method, he assumed that this method gave the more nearly correct rates. Masure's results (*6*) would indicate that the data presented herein may be slightly low.

The temperature of the respiration chambers was controlled by placing them in the constant-temperature rooms of the cold-storage laboratory at the Arlington Experiment Farm.

The percentage dry-matter content was determined by drying duplicate 50-gm. samples to constant weight at 70° C. in vacuum. Sugar determinations were made by the Munson-Walker-Bertrand method on an alcoholic extract of the ground tissue. Titratable-acidity determinations were made on a water extract of the ground tissue, and the end point was determined electrometrically. Alcohol determinations were made by the method described by Thomas (*12*). This consists of removing the acetaldehyde from a steam distillate of the tissue, oxidizing the alcohol to acetic acid, and titrating the acid.

PRESENTATION OF RESULTS

Respiration Studies With Strawberries and Comparison of Varieties

The fruit for these investigations was obtained almost entirely from the test plots of the United States Department of Agriculture at Glenn Dale, Md. Usually the berries were picked one day, allowed to come to the temperature desired overnight, and the respiratory rate determinations were started the day following picking and run for 2 to 3 days. The determinations were made during five seasons, but the same varieties were not used during all seasons. Generally duplicate determinations (on 500- to 750-gm. samples at 60° F.) were made on full-ripe fruit of each variety. The duplicates agreed very well, and the data presented in table 1 represent the average of the duplicate determinations.

TABLE 1.—*Respiratory rates of different varieties of strawberries at 60° F.*

Variety	CO_2 evolved per kilogram of fresh weight per hour					
	1929	1930	1931	1932	1933	Average
	Milligrams	*Milligrams*	*Milligrams*	*Milligrams*	*Milligrams*	*Milligrams*
Howard 17	75.9	93.1	72.6	87.8		82.3
Missionary	90.8	102.6		88.8	72.7	88.7
Chesapeake		71.1			76.9	74.0
Blakemore		86.1	106.2	96.4	71.7	90.2
Belt (William Belt)			103.4	89.5		96.5
Gassett			79.1	65.0		72.0
Redheart			109.2	95.2	89.9	98.1
Southland				78.5	63.0	70.8
Portia				72.2		72.2
Aroma				100.3		100.3
Klondike				100.6	85.5	93.0
Fairfax				93.1	76.0	84.5
Big Late				64.6		64.6
Bellmar					65.3	65.3
Cooper					85.0	85.0
Dorsett				79.0	65.2	72.1
Narcissa					85.6	85.6
Big Joe					74.8	74.8
U. S. D. A. 542	73.0			86.6		79.8
U. S. D. A. 668	99.3	76.9				88.1
U. S. D. A. 682		92.4				92.4
U. S. D. A. 903			88.8			88.8
U. S. D. A. 1025			83.5			83.5
U. S. D. A. 911			99.0	93.2	72.4	88.2
U. S. D. A. 1030			75.0			75.0
U. S. D. A. 652				59.5	48.5	54.0
Average						80.8

The data show that the varieties differed greatly in respiratory activity; they also indicate considerable seasonal variation within a variety. Thus the Howard 17 variety varied from 72.6 mg. CO_2 per kilogram-hour in one season to 93.1 in another. Even greater variability was apparent in the Missionary with a high reading of 102.6 mg. o CO_2 and a low reading of 72.7 mg.

Nine varieties and seedlings were used in both 1932 and 1933. The respiratory rates for these averaged 17.8 percent lower in 1933 than in 1932. The rates in 1932 averaged 7.5 percent lower than in 1931 with six varieties giving a comparison. Five of these varieties were consistent with the average in showing a lower rate in 1932. Insufficient comparisons were possible between the other years, to show whether there were significant differences.

Although the varieties apparently differed considerably under similar climatic and cultural conditions, such differences were greatly masked by variations between seasons; and in these the varieties did not always show consistency. Thus Missionary was considerably higher than Chesapeake in 1930 but somewhat lower in 1933; Howard 17 was higher than Blakemore in 1930 but lower in 1931 and 1932. In general, however, the varieties maintained the same relative positions in the different seasons. A statistical examination of the data for the nine varieties that were compared in 1932 and 1933 (by analysis of variance with the interaction of varieties with years as the error mean square) showed that there were very highly significant differences between varieties. Considering the results for all seasons the varieties Missionary, Blakemore, Redheart, Belt, Aroma, and Klondike appear to have relatively high respiratory activity, the varieties Chesapeake, Gassett, Southland, Portia, Big Late, Bellmar, Dorsett,

and Big Joe relatively low respiratory activity, and U. S. D. A. 652 [3] the lowest respiratory activity. Other varieties, such as Howard 17, Fairfax, Cooper, and Narcissa, were intermediate in respiratory activity.

Most of the varieties with high respiratory activity, such as Blakemore, Redheart, Aroma, and Klondike, have relatively firm berries that hold up well during shipment; and many of the varieties with low respiratory activity, such as Gassett, Southland, Big Late, Bellmar, Dorsett, and U. S. D. A. 652, have soft berries of poor shipping quality. Thus high respiratory activity, as determined on a fresh-weight basis, appears to be associated with good keeping or shipping quality in strawberry varieties. This is in agreement with results of Overholser et al. (*8*), who found the respiratory rates of several firm varieties to be greater than those for several soft varieites.

Relation of Respiratory Activity to Percentage Dry-Matter Content of Strawberries

It has been shown herein that respiratory activity of strawberries when computed on a fresh-weight basis differed greatly, both among varieties and for the same variety under different seasonal conditions. In an earlier report (*3*) it was shown that the percentage of dry matter in strawberries varied greatly, and that the respiratory activity was closely correlated with the dry-matter content. Data presented in the previous report have been incorporated with additional data to show this relationship (table 2). The different lots have been arranged in the order of decreasing percentage dry-matter content. As will be seen, there was also a tendency for the respiratory activity determined on a fresh-weight basis to decrease. Between percentage of dry matter and milligrams of CO_2 evolved per kilogram of fresh weight per hour there was a rather high coefficient of correlation [4] of $+0.718$, with a coefficient of regression of $+6.65\pm0.89$, indicating that for each increase of 1 percent in dry-matter content there was a corresponding increase of approximately 6.65 milligrams per kilogram-hour in respiratory activity determined on a fresh-weight basis. During certain seasons several pickings were made of the same variety, and generally both the percentage of dry matter and the respiratory activity increased for later samples. An increase in rate of respiration with advance of season has also been reported by Overholser et al. (*8*).

[3] The U. S. D. A. numbers refer to unnamed seedling selections in the strawberry breeding investigations of the United States Department of Agriculture.

[4] The transformation of r to t resulted in a value of 7.44. With 52 degrees of freedom, the correlation is highly significant (*10, p. 183*).

TABLE 2.—*Respiratory rates at 60° F. in relation to dry weights of different varieties and pickings of strawberries*

Variety	Picking date	Dry-matter content	Respiratory rates: CO_2 evolved per kilogram of fresh weight per hour	Respiratory rates: CO_2 evolved per 100 grams of dry weight per hour	Berries found decayed at end of experiment
		Percent	*Milligrams*	*Milligrams*	*Percent*
U. S. D. A. 911	June 6, 1932	12.2	88.4	72.5	1
Dorsett	June 8, 1932	12.0	91.4	76.2	16
Fairfax	do	11.5	93.1	80.9	4
Missionary	do	11.4	88.8	77.9	7
Belt	June 6, 1932	11.05	89.5	81.0	0
Redheart	June 8, 1932	10.8	100.3	92.8	1
Do	June 5, 1933	10.8	89.9	83.2	0
Cooper	do	10.55	85.0	80.6	33
Howard 17	June 8, 1932	10.5	95.6	91.0	5
Portia	June 6, 1932	10.45	72.2	69.1	4
U. S. D. A. 911	May 31, 1932	10.35	98.1	94.8	0
Aroma	June 6, 1932	10.15	100.3	98.8	10
Redheart	do	10.1	90.1	89.2	5
Southland	June 8, 1932	9.9	80.1	80.9	7
U. S. D. A. 924	June 5, 1933	9.9	79.5	80.3	53
Southland	June 6, 1932	9.8	78.1	79.7	4
U. S. D. A. 542	May 31, 1932	9.7	86.7	89.4	4
Fairfax	do	9.5	80.6	84.8	4
Do	June 5, 1933	9.45	76.3	80.7	20
Big Joe	do	9.4	74.8	79.6	48
U. S. D. A. 911	June 1, 1933	9.4	72.4	77.0	
Dorsett	June 5, 1933	9.1	76.0	83.5	18
Do	May 31, 1932	9.05	66.5	73.5	1
Gassett	June 8, 1932	8.8	65.7	74.7	14
Redheart	May 31, 1932	8.75	95.4	109.0	5
Blakemore	June 5, 1933	8.7	82.3	94.6	6
U. S. D. A. 1009	May 31, 1932	8.6	89.7	104.3	0
Klondike	June 1, 1933	8.5	85.5	100.6	
Chesapeake	June 5, 1933	8.45	76.9	91.0	7
U. S. D. A. 904	June 6, 1932	8.35	87.0	104.2	2
Gassett	do	8.35	64.2	76.9	4
U. S. D. A. 674	May 31, 1932	8.15	71.5	87.7	8
U. S. D. A. 694	do	8.15	78.8	96.7	7
Big Late	June 8, 1932	8.1	64.6	79.8	8
Southland	June 5, 1933	8.05	62.4	77.5	5
Do	June 1, 1933	8.0	63.5	79.4	
U. S. D. A. 652	June 8, 1932	7.9	56.8	71.9	5
Thomas	do	7.9	57.4	72.7	
Bellmar	June 5, 1933	7.85	69.4	88.4	9
Howard 17	May 31, 1932	7.8	80.0	102.6	9
Fairfax	June 1, 1933	7.8	75.7	97.0	
Narcissa	June 5, 1933	7.75	85.6	110.4	24
Thomas	June 6, 1932	7.75	57.3	73.9	4
Bellmar	June 1, 1933	7.7	65.3	84.8	
Blakemore	May 31, 1932	7.65	96.4	126.0	6
Southland	do	7.5	77.4	103.2	6
Missionary	June 1, 1933	7.5	72.7	96.9	
U. S. D. A. 592	do	7.1	50.8	71.5	
Dorsett	do	7.1	54.4	76.6	
U. S. D. A. 663	do	7.05	52.8	75.9	
Blakemore	do	6.8	61.0	89.7	
U. S. D. A. 652	June 5, 1933	6.7	54.1	80.7	88
Do	May 31, 1932	5.9	62.1	105.2	19
Do	June 1, 1933	5.8	42.8	73.8	
Mean		8.84	76.2		

When the respiratory rates were computed on a dry-weight basis (table 2) the variability was reduced, and there was no longer a correlation between dry weights and respiratory rates. However, the respiratory activity for any one variety also varied greatly on the dry-weight basis, and there does not appear to have been any consistent difference in respiratory activity between varieties on this basis. The respiratory rates in milligrams per 100 gm. of dry weight per hour varied from about 70 to 125. It was thought that decay might have been responsible for the high rates in some instances.

When the experiments were ended the number of soft or decayed berries was generally determined. In a few instances the percentages of decayed fruit were rather high, but such lots showed only moderate respiratory activity, and the lots with high respiratory activity did not have excessive decay, indicating that the decay was not responsible for the high respiratory activity found with certain lots. The difference in respiratory activity on a dry-weight basis might be due to differences in the proportion of protoplasm or of respiratory enzymes to sugars and acids. This is indicated by the work of Overholser and Claypool (7), who increased the respiratory rate of strawberries by

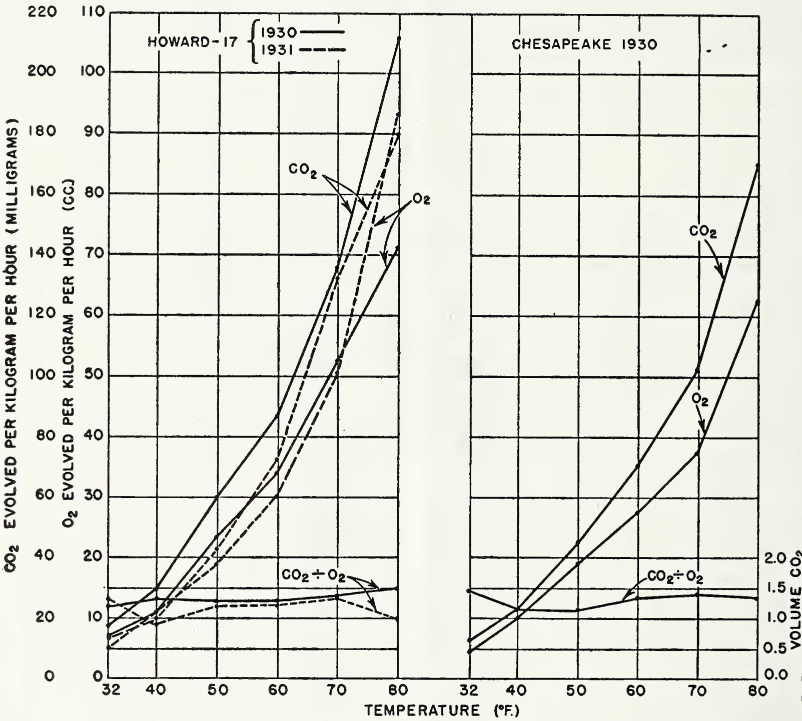

FIGURE 1.—Respiration of strawberries of two varieties in relation to temperature.

nitrogen ($(NH_4)_2SO_4$) fertilization. As the nitrogen fertilization decreased the firmness of the fruit it seems likely that it may have reduced the dry weight also. Thus nitrogen fertilization, by increasing the nitrogen content of the fruit, would increase the respiratory rate per unit of dry weight.

From the results presented in this circular it would seem desirable to express respiratory activity on a dry-weight basis, in comparing varieties or cultural treatments in which the dry weights of the fruit may vary, as on a fresh-weight basis, differences observed may reflect simply differences in moisture content, but of course inversely.

Relation of Temperature to Respiratory Activity of Strawberries

The effect of temperature on the respiratory activity of strawberries is shown in table 3 and figure 1. The size of the samples varied from

200 gm. at 80° F. to 2,000 gm. at 32°. At 32° the rates varied from 12.4 to 18.0 mg. of CO_2 per kilogram of fresh weight per hour. As with other fruits (*2*), the rates increased rapidly with temperature and reached as much as 211.1 mg. at 80°. The rates at 80° averaged about 13 times those at 32°, and at 70° nearly 9 times those at 32°; at 60° the rates averaged over 5 times those at 32°; at 50° about 3.5 times; and at 40° about 1.5 times. In figure 1 the O_2 consumed in respiration is shown also. The results of the O_2 measurements form curves similar to those for CO_2 determinations. Gerhart (*1*) has shown a corresponding increase in respiratory activity (O_2 consumed) with increased temperature between 5° and 30° C. (41° and 86° F.) with a maximum at 36.5° C. (97.7° F.). The rate fell off rapidly above 36.5° C.

TABLE 3.—*Relation of temperature to respiratory rates of strawberries and raspberries*

[Samples of strawberries varied from 200 gm. at 80° F. to 2,000 gm. at 32°]

Variety	Date of determination	CO_2 evolved per kilogram of fresh weight per hour at—					
		80° F.	70° F.	60° F.	50° F.	40° F.	32° F.
	1930						
Strawberries:		*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*
Chesapeake	June 2 to June 4	169.2	102.6	71.1	45.1	23.3	12.4
Howard 17	May 30 to June 2	211.1	137.1	87.0	59.5	30.5	17.3
	1931						
Do	June 5 to June 9	179.9	132.0	72.6	43.1	20.0	13.5
Average 1930 and 1931		186.7	123.9	76.9	49.2	24.6	14.4
Ratio to 32° rate		13.0	8.6	5.3	3.4	1.7	1.0
	1929						
Howard 17	May 22 to May 25			68.0		16.4	13.6
Do	May 27 to May 29			76.5		24.3	14.7
Do	May 31 to June 1			83.2		26.3	15.2
Missionary	May 22 to May 25			92.2		29.6	18.0
Do	May 31 to June 1			89.4		30.7	17.1
U. S. D. A. 542	do			73.0		25.2	15.1
Average 1929, 1930, and 1931.				79.2		25.1	15.2
Ratio to 32° rate				5.2		1.7	1.0
Raspberries:							
Latham	June 27 to July 3			[1] 82.2		[2] 30.7	[3] 17.5
Cumberland	do			[1] 100.7		[2] 38.5	[3] 19.9
U. S. D. A. 332	do			[1] 87.5		[2] 36.9	[3] 25.1
Average 1929				90.1		35.4	20.8
Ratio to 32° rate				4.3		1.7	1.0

[1] Determinations made June 27 to June 29; samples of 500 gm.
[2] Determinations made June 27 to July 1; samples of 1,000 gm.
[3] Determinations made June 27 to July 3; samples of 1,500 gm.

The ratios of CO_2 to O_2 shown in figure 1 varied from about 1.0 to 1.5, but there appeared to be no consistent relation to temperature. The average ratio at all temperatures was 1.22 ± 0.03, which would indicate that both sugar and acid were utilized in respiration.

At the lower temperatures (50° to 32° F.) there was little or no change in rate with time. At the higher temperatures the rates generally increased very rapidly with time. At 60°, 70°, and 80° the

respiratory rates of the last determinations, made 2 to 4 days after the first were 33 to 52 percent higher than the first, and at 40° and 32° the increase with time averaged 7 and 3 percent, respectively.

Relation of Humidity to Respiratory Activity of Strawberries

The relative humidity was varied by placing different concentrations of sulfuric acid in the bottom of the respiration chambers (desiccators). The concentrations of acid were adjusted to give the relative humidities shown in table 4 according to tables given by Stevens (*11*). The actual humidities obtained were not determined and may have varied somewhat from those given, particularly at the lower extremes.

Table 4.—*Relation of humidity at 60° F. to respiratory rate of Howard 17 strawberries*

Date	CO_2 evolved per kilogram of fresh weight per hour at a relative humidity of—					
	100 percent	80 percent	60 percent	40 percent	20 percent	0 percent
1930	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*
May 26 to May 28	80.1	83.0	81.8	81.4	79.4	83.1
May 28 to May 30	83.1	84.0	79.4	80.2	81.7	85.2
Average	81.6	83.5	80.6	80.8	80.6	84.1

ANALYSIS OF VARIANCE

Comparison of—	Degrees of freedom	Mean square	*F*	Significance
Time of picking	1	1.9	1.0	Not significant.
Humidities	5	5.1	2.7	Do.
Time × humidities	5	1.9		
Total	11			

With material that has a relatively high water content, such as strawberries, it did not seem likely that the respiratory activity would be influenced by the relative humidity of the surrounding atmosphere. The data in table 4 do not show any effect of relative humidity on respiratory activity of two lots of Howard 17 strawberries at 60° F. (*10, p. 336*). Gerhart (*1*), on the other hand, reported a temporary increase in respiration with low humidity.

Relation of Maturity to Respiratory Activity of Strawberries

The respiratory activity of strawberries at three stages of maturity or ripeness was determined, and the results are presented in table 5. The ripe stage consisted of berries that were fully colored; in the half-ripe stage about half of the surface of the fruit was light red or there was a light-pink color over the entire surface; and the berries were regarded as in the green stage when just beginning to show a tinge of pink until they were half pink. The results show a rather consistent linear increase in respiratory activity with increased ripeness. The

half-ripe berries evolved an average of 16 percent less CO_2 and the green berries 30 percent less than the fully ripe ones. Whether this was due to increased dry weight with maturity or to some other factor was not determined. In good agreement with these results Overholser et al. (*8*) report a 50-percent increase in respiratory rate from immature to mature berries.

TABLE 5.—*Relation of stage of maturity to respiratory rates of strawberries of three varieties*

Variety	Season	Temperature	CO_2 evolved per kilogram of fresh weight per hour when berries were—		
			Ripe	Half ripe	Green
		°F.	*Milligrams*	*Milligrams*	*Milligrams*
Howard 17	1929	60	76.5	65.8	49.5
		40	24.3	18.8	14.7
		32	14.7	12.6	10.4
U. S. D. A. No. 668	1930	60	76.9	63.2	58.6
U. S. D. A. No. 27	1930	60	61.6	52.2	44.9
Average			50.8	42.5	35.6
Ratio to ripe			1.0	.84	.70

AEROBIC AND ANAEROBIC RESPIRATION OF STRAWBERRIES

Anaerobic conditions were obtained by flushing out the respiration chambers with nitrogen gas after the fruit was sealed in. Nitrogen was substituted for oxygen in the attached cylinder, so that as any oxygen remaining was used in respiration it was replaced with nitrogen. Data obtained from the runs for the first day were discarded in order to allow time for the removal of any oxygen that was not flushed out.

The results presented in table 6 and figure 2 indicate that in many instances the respiratory activity as measured by CO_2 evolved was maintained under anaerobic conditions for several days at a rate not greatly less than under aerobic conditions. Assuming the complete oxidation of a hexose sugar in the presence of O_2 the reaction would be:

$$C_6H_{12}O_6+6O_2\rightarrow 6H_2O+6CO_2+673{,}000 \text{ cal./mole.}$$

In the absence of O_2 alcohol is formed, as indicated in table 7. The amount of alcohol found was not equal to the loss in sugar, possibly due to the loss by vaporization of some of the alcohol formed and probably to the formation of acetaldehyde or other substances instead of alcohol in the breaking down of the sugars. The results (table 7) indicate that acid is not lost during intramolecular respiration to as great an extent as during respiration in air. The formation of alcohol from sugar by intramolecular respiration might proceed according to the following equation:

$$C_6H_{12}O_6\rightarrow 2C_2H_5OH+2CO_2.$$

This reaction would produce relatively little or no heat as the heat produced by the complete combustion of two moles of C_2H_5OH is almost as much as that produced by one mole of $C_6H_{12}O_6$. According to the above reactions one unit of sugar produces only one-third as much CO_2 under anaerobic conditions as under aerobic conditions. As the rate at which CO_2 was evolved was nearly as great in an

atmosphere of nitrogen as in air, the rate of sugar loss would be nearly three times as rapid in nitrogen as in air. Even after extended periods in nitrogen the rate of respiration was generally maintained at nearly 50 percent of the rate in air, which would indicate a 150-percent destruction of sugar in nitrogen as compared with air. The limited analyses in table 7 indicate that there was a much greater

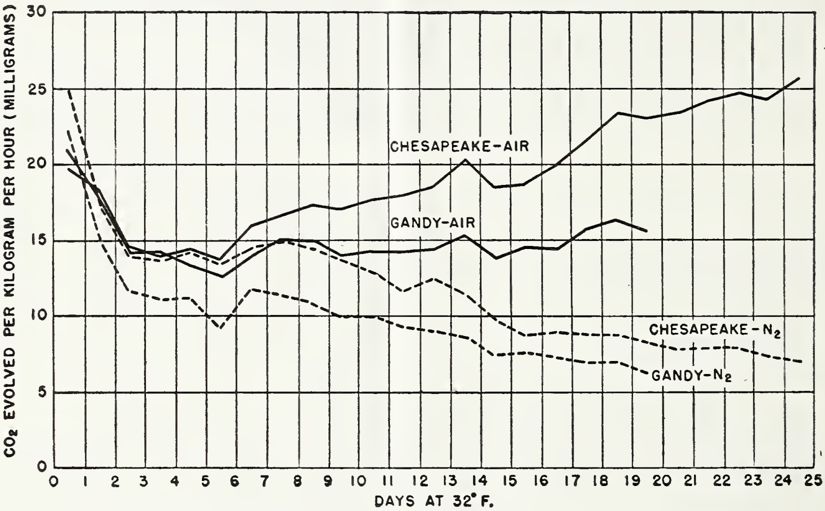

FIGURE 2.—Respiration of strawberries in air and in nitrogen at 32° F.

loss of sugar in nitrogen than in air, thus confirming the conclusion arrived at from a consideration of the respiration results.

TABLE 6.—*Comparison of aerobic and anaerobic respiration of strawberries of four varieties*

Variety	Period from start	Date	Temperature	Days	CO_2 evolved per kilogram of fresh weight per hour in— Air	N_2	Ratio N_2/Air
	Days	*1929*	°*F.*	*Number*	*Milligrams*	*Milligrams*	
Howard 17	2 to 4	May 22 to May 25	60	3	68.0	61.1	0.90
	2 to 4	do	40	3	16.4	18.3	1.11
	2 to 4	do	32	3	13.6	12.7	.93
U. S. D. A. unnumbered.	2 to 4	June 3 to June 6	60	3	87.0	46.4	.53
	2 to 19	June 3 to June 21	40	18	31.6	12.6	.40
	2 to 22	June 3 to June 24	32	21	12.0	5.9	.49
		1930					
Gandy	3 to 5	June 7 to June 10	32	3	13.9	11.3	.81
	6 to 12	June 12 to June 18	32	6	14.2	10.3	.73
	13 to 22	June 18 to June 27	32	9	14.9	7.5	.50
Chesapeake	3 to 9	June 7 to June 16	32	9	20.8	17.1	.82
	3 to 11	do	32	9	18.2	12.6	.69
	10 to 19	June 16 to June 26	32	10	2 .3	10.3	.42
	3 to 11	June 7 to June 16	32	9	15.1	14.1	.93
	10 to 19	June 16 to June 26	32	10	19.1	10.6	.55
	20 to 31	June 26 to July 7	32	11	26.6	7.4	.28
Average					26.4	17.2	.65

TABLE 7.—*Effect of air and nitrogen atmospheres on composition of strawberries of four varieties in storage at different temperatures*

Variety	Date	Storage temperature	Dry weight		Sugars				Acidity		Alcohol	
					Reducing		Sucrose					
			Air	N_2	Air	N_2	Air	N_2	Air	N_2	Air	N_2
	1929	*°F.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Howard 17	May 22	(1)	8.55	-----	3.53	-----	0.64	-----	0.90	-----	0.003	-----
	May 25	60	8.10	7.20	3.27	3.19	.39	0.26	.94	0.83	-----	-----
	June 19	32	-----	-----	-----	-----	-----	-----	.60	.87	.008	0.214
U.S.D.A. (unnumbered).	June 3	(1)	-----	-----	3.52	-----	.16	-----	1.02	-----	-----	-----
	June 6	60	-----	-----	3.14	3.05	.15	.09	.88	.83	-----	-----
	June 21	40	-----	-----	3.28	2.41	.21	.10	.78	.87	-----	.353
	June 24	32	-----	-----	3.40	2.85	.08	.18	.70	.81	.005	.109
Gandy	June 6	(1)	-----	-----	-----	-----	-----	-----	-----	-----	.002	-----
	June 12	32	-----	-----	-----	-----	-----	-----	-----	-----	.005	.126
	June 19	32	-----	-----	-----	-----	-----	-----	-----	-----	.004	.229
	June 27	32	-----	-----	-----	-----	-----	-----	-----	-----	.007	.412
Chesapeake	June 6	(1)	-----	-----	-----	-----	-----	-----	-----	-----	.002	-----
	June 16	32	-----	-----	-----	-----	-----	-----	-----	-----	.005	.251
	June 26	32	-----	-----	-----	-----	-----	-----	-----	-----	.016	.449

1 At harvest.

It is of interest to note that the strawberries continued to give off CO_2 even after 3 to 4 weeks without oxygen. This would indicate that the fruit was still alive if respiration may be considered a criterion of a living condition. Little or no decay developed on the berries in nitrogen; however, they generally had developed an off-flavor and became soft and collapsed soon after they were exposed to air.

Respiration of Raspberries

Limited results on the effect of variety and temperature on the respiratory activity of raspberries are presented in table 3. Single determinations were made with samples of 500 gm. at 60° F., 1,000 gm. at 40°, and 1,500 gm. at 32°. The fruit was obtained from Glenn Dale, Md., and handled the same as the strawberries. The Cumberland berries were smallest and averaged 1.25 gm.; the Lathams were largest (2.15 gm.); and the seedling berries were intermediate (1.8 gm.).

The respiratory rate of the raspberries was of the same order of magnitude as that of the strawberries but averaged somewhat higher, particularly at the lower temperatures. Under the conditions of this experiment the Latham (red raspberry) variety respired at a consistently lower rate than the Cumberland (black raspberry). The purple raspberry seedling (U. S. D. A. 332) had the highest rate at 32° but was intermediate between the red and black raspberries at the other temperatures. The respiratory rate of raspberries at 60° F. averaged 4.3 times as great as that at 32°.

DISCUSSION

Strawberries have a relatively short life after harvest compared with such other fruits as apples, pears, and citrus. Associated with this short life is a relatively high rate of respiration. Among the strawberry varieties, however, a high rate of respiration on a fresh-weight basis was associated with firm berries of relatively good

shipping quality. As might be expected, the firm varieties have a high percentage of total solids, and the high respiratory activity of the firm berries was presumably due very largely to the greater amount of respirable material per unit of fresh weight.

The respiratory rates at 32° F. as indicated by the volume of CO_2 evolved, varied from 12.4 to 18.0 mg. of CO_2 per kilogram (fresh-weight basis) per hour, and averaged 15.2 (table 3). Assuming that the CO_2 evolved resulted from the complete oxidation of a hexose sugar, this average would be equivalent to the loss of 0.025 gm. of sugar per 100 gm. of strawberries in 24 hours. Assuming an average sugar content of about 4.5 percent, this would represent a loss per day at 32° of only about 0.55 percent of the sugar present. At 60° the loss would be 5.2 times as great (table 3) or about 2.9 percent per day, or 8.7 percent in 3 days, and at 80° about 7.2 percent per day or 21.6 percent in 3 days. The results of analyses given in table 7 indicate an actual loss in 3 days at 60° of 12.8 percent in the case of Howard 17 and 10.6 percent in the case of the unknown seedling. These percentages are somewhat higher than those computed from the average respiratory rates but do not necessarily represent the actual loss, as the relative loss of moisture during this period would affect the results. On the basis of the respiratory rates given for these lots in table 6, the sugar loss computed from the respiratory rate was 8.0 percent in the case of Howard 17, and 11.8 percent in the case of the unnumbered U. S. D. A. seedling. These results indicate a considerable loss of food value at higher temperatures to which strawberries may be subjected.

Rose and Gorman (*9*) estimate that the heat of respiration of a carload of strawberries, or about 7 tons, during cooling from 80° to 40° F. would melt 1 ton of ice in 2 days. Their calculations were based on some of the data (2) presented herein. Based on the average rates of respiration at the various temperatures presented in table 3 the heat of respiration of a 7-ton carload of the berries during 1 day at 32° would melt 152 pounds of ice; at 40°, 258 pounds; at 50°, 517 pounds; at 60°, 790 pounds; at 70°, 1,310 pounds; and at 80°, 1,975 pounds. These figures are based on the assumptions that the temperature remains constant and that the CO_2 output is due to the complete oxidation of a hexose sugar. The heat of respiration would be considerably less if the CO_2 were derived in large part from the oxidation of acid, as was indicated by the respiratory ratios shown in figure 1. These results indicate the importance of the prompt cooling of strawberries in order to reduce both the ice meltage due to the heat of respiration and the loss of food value in the fruit.

SUMMARY

The respiratory rates of various strawberry varieties were found to differ greatly at a given temperature.

The varieties also differed greatly in dry-matter content.

The differences in respiratory activity per unit of fresh weight of the varieties were largely correlated with the differences in dry weight.

Seasonal differences in respiratory activity for a particular variety were also directly correlated with differences in dry weight.

High respiratory activity on a fresh-weight basis was associated with firm berries of good shipping quality.

The respiratory rates of strawberries increased about 50 percent from the immature to the mature stage. There was also an increase in respiratory activity of ripe berries picked later in the season.

The respiratory rate of strawberries increased greatly with a rise in temperature and averaged 13 times as great at 80° F. as at 32°.

The relative humidity of the surrounding atmosphere had no effect on the respiratory rate of Howard 17 strawberries.

Under anaerobic conditions the rate at which CO_2 was evolved gradually decreased, and with extended periods became less than 50 percent of the rate in air.

With intramolecular respiration alcohol was formed and the loss of sugar was more rapid than with aerobic respiration.

A limited trial of three varieties indicated that the respiratory rate of raspberries was of approximately the same order of magnitude as that of strawberries.

LITERATURE CITED

(1) Gerhart, Arthur R.
1930. respiration in strawberry fruits. Bot. Gaz. 89: 40–66, illus.

(2) Haller, M. H., Harding, P. L., Lutz, J. M., and Rose, D. H.
1932. the respiration of some fruits in relation to temperature. Amer. Soc. Hort. Sci. Proc. (1931) 28: 583–589.

(3) ——— Harding, P. L., and Rose, Dean H.
1933. the interrelation of firmness, dry weight, and respiration in strawberries. Amer. Soc. Hort. Sci. Proc. (1932) 29: 330–334. illus.

(4) ——— and Rose, D. H.
1932. apparatus for determination of CO_2 and O_2 of respiration. Science 75: 439–440, illus.

(5) Magness, J. R., and Diehl, H. C.
1924. physiological studies on apples in storage. Jour. Agr. Res. 27: 1–38, illus.

(6) Masure, M. P.
1939. some comparisons of methods of measuring fruit respiration. Amer. Soc. Hort. Sci. Proc. (1938) 36: 223–229.

(7) Overholser, E. L., and Claypool, L. L.
1932. the relation of fertilizers to respiration and certain physical properties of strawberries. Amer. Soc. Hort. Sci. Proc. (1931) 28: 220–224.

(8) ——— Hardy, Max B., and Locklin, H. D.
1931. respiration studies of strawberries. Plant Physiol. 6: 549–557.

(9) Rose, Dean H., and Gorman, E. A., Jr.
1936. handling, precooling, and transportation of florida strawberries. U. S. Dept. Agr. Tech. Bul. 525, 58 pp., illus.

(10) Snedecor, George W.
1938. statistical methods applied to experiments in agriculture and biology. Rev. ed., 388 pp., illus. Ames, Iowa.

(11) Stevens, Neil E.
1916. a method for studying the humidity relations of fungi in culture. Phytopathlogy 6: [428]–432.

(12) Thomas, Meirion.
1925. the controlling influence of carbon dioxide v. a quantitative study of the production of ethyl alcohol and acetaldehyde by cells of the higher plants in relation to concentration of oxygen and carbon dioxide. Biochem. Jour. 19: [927]–947, illus.

U. S. GOVERNMENT PRINTING OFFICE: 1941

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - Price 5 cents